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Suppression of Coal Dust Explosion by Water Barrier in a Conveyor Belt Entry

By I. Liebman and J. K. Richmond

UNITED STATES DEPARTMENT OF THE INTERIOR

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On pages 24 and 25, the illustrations were switched by the printer. The captions are in the right places, but the illustration appearing on page 24 should be on page 25 and vice versa.

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UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary
BUREAU OF MINES

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SUPPRESSION OF COAL DUST EXPLOSION BY WATER BARRIER IN A CONVEYOR BELT ENTRY

by

I. Liebman[1] and J. K. Richmond[2]

ABSTRACT

The Bureau of Mines conducted experiments on coal dust explosion suppression. The investigation took place on a beltway in the double-entry of the Bureau's Experimental Mine. Using conditions that simulate those in a working mine, the investigation showed that a coal dust explosion can be readily initiated in a conveyor belt entry. Also, the explosion can spread into adjacent entries through opened crosscuts (stopping destroyed by explosion) to propagate for long distances even though the adjacent entries are rock dusted in compliance with regulations.

Passive water barriers (water-filled tubs) were found to be effective in suppressing explosions on a beltway; however, barrier efficiency was reduced by opened crosscuts. The study indicated that the beltway barrier should be the distributed type consisting of continuous rows of water-filled tubs covering long distances along the entry.

A plan is outlined for the installation of a water barrier system in a working coal mine for the protection of a beltway.

INTRODUCTION

Generalized rock dusting is currently the primary means of defense against coal dust explosions in U.S. mines. It is well recognized, however, that many regions in mines are difficult or impossible to rock dust adequately. Seven such potentially dangerous areas are (1) conveyor beltways, (2) transfer points, (3) wet roadways, (4) parked mine cars, (5) return airways, (6) longwalls, and (7) isolated sections. To augment current explosion defense, the Bureau of Mines is conducting research to test and develop explosion barriers that can be used as a supplement to rock dusting in hazardous mine regions.

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This report describes recent Bureau of Mines efforts with passive water barriers to protect a belt conveyor road. The explosion trials were conducted in a simulated belt entry in the Bureau's Experimental Mine at Bruceton, Pa. The purpose of the trials was to characterize explosions on a beltway, determine the value of passive water barriers to suppress such explosions, and assess the potential of an explosion to propagate on a belt conveyor roadway that has been rock dusted in compliance with regulations.

PASSIVE WATER BARRIERS

Passive water barriers are being used in underground coal mines in foreign countries for defense against coal dust explosions. The passive water barrier is typically made up of numerous water-filled containers mounted in the vicinity of the mine roof. During a coal dust explosion, the dynamic wind forces generated ahead of the propagating flame tip or fragment the container to release and disperse the water to suppress the oncoming flame.

In previous work (3)[3] with passive water barriers, it was established that a West German-made barrier (water-filled tub) is adequate for arresting moderate to strong coal dust explosions. The tub (fig. 1, top) is made of polyvinyl chloride (PVC), holds approximately 180 lb of water, and was found to operate best when supported rigidly in a metal frame by means of its total upper lip resting on a frame. This barrier proved to be effective against explosions propagating at flame speeds of 250 ft/sec to better than 1,000 ft/sec (3). The Bureau developed several other water barriers (modified tubs) that were tested successfully against weak explosions (4). The Bureau has recently developed a new modified barrier tub (fig. 1, bottom) that is effective against slow-moving explosions. Both the German tub and the modified tub were used in the explosion suppression trials. The appendix includes a description of the modified tub and design and construction details of a proposed barrier system for a belt conveyor roadway in a working mine.

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

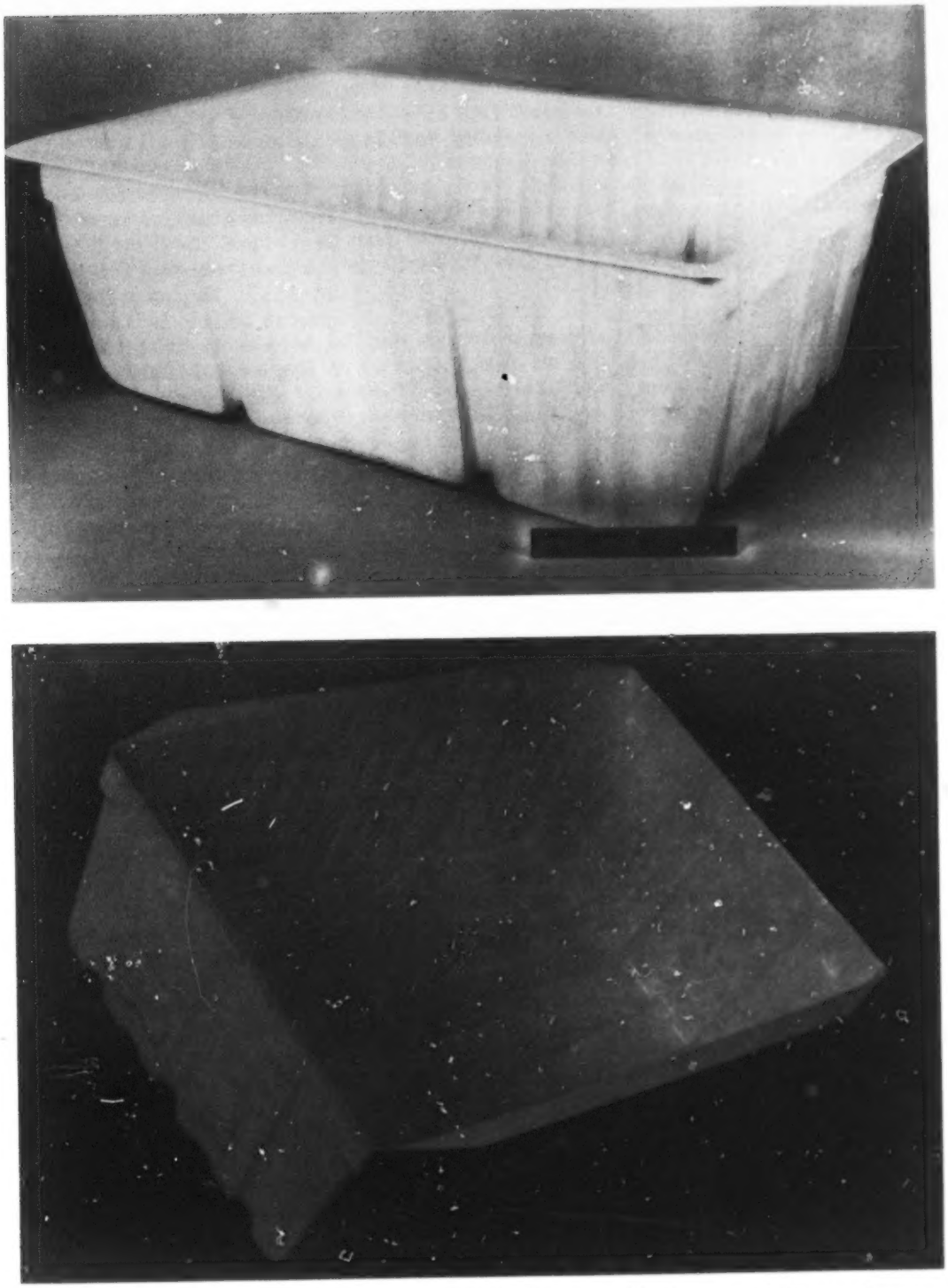

FIGURE 1. - German water barrier tub (top) and modified water tub (bottom).

EXPLOSION TEST FACILITY

Previous explosion suppression trials were conducted by the Bureau in the single entry (main entry) of the Experimental Mine. The trials of present report were accomplished in the same facility, expanded to a double-entry configuration. A plan view of this expanded facility is shown in figure 2.

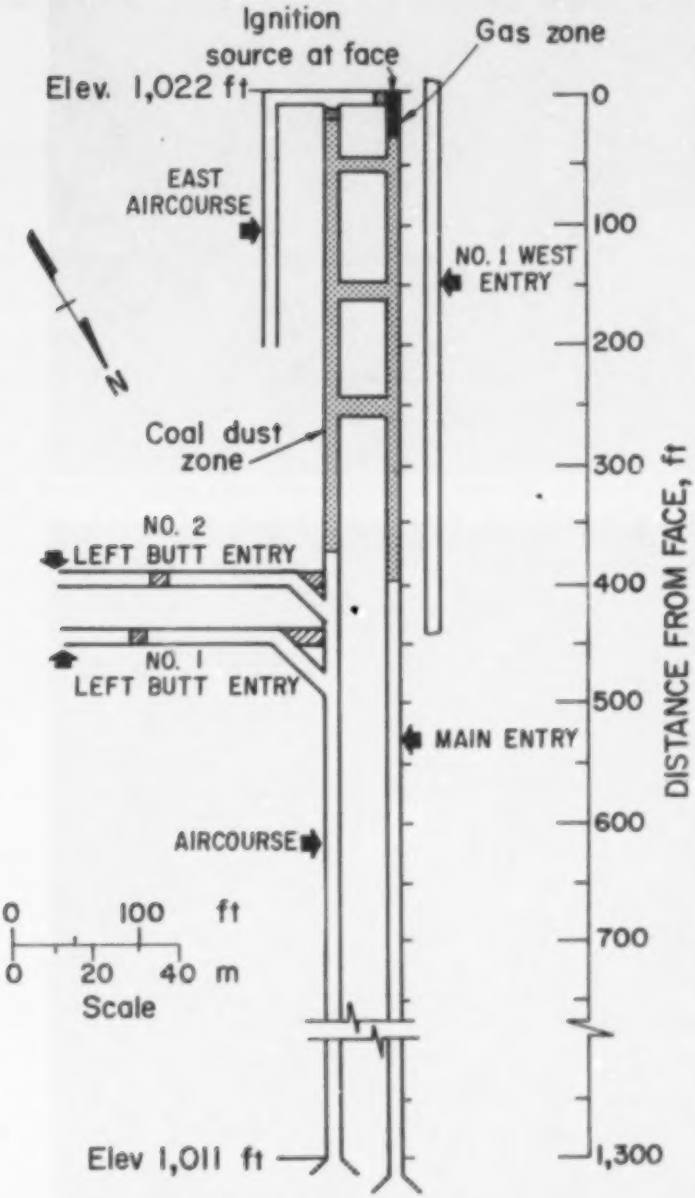

FIGURE 2. - Map of Bureau's double-entry Experimental Mine.

The main entry and its instrumentation have been described in detail in a previous manuscript (3, pp. 14-15). The parallel aircourse entry is identical in size and is instrumented in a manner similar to that of the main entry. In brief, the entries are about 9 ft wide by 6 ft high and about 1,000 ft long. Crosscuts of similar cross section to the parallel entries connect the two entries at 50, 160, and 250 ft from the closed end (face). Instrumentation consisted of flame sensors, pressure transducers, drag and pilot probes and dust probes. The belt system, located in the main entry, was made up of either (1) a simulated belt consisting of 9-in-wide by 10-ft-long plastic strips laid end to end along the entry for distances of 100 ft or more, suspended 2 ft or 4 ft above the mine floor by strings tied to the roof, or (2) a commercial conveyor beltway 2 ft wide by 2 ft high by 200 ft long and bolted to the mine floor.

Test zones prepared in the mine for the explosion trials consisted of (1) 15- to 40-ft-long flammable natural gas-air mixtures confined to the face region of the main entry by a thin plastic diaphragm,

(2) coal-rock dust mixtures in the main entry extending from the end of the gas zone to about 350 ft from the face, (3) coal-rock dust mixtures in the crosscuts, (4) coal-rock dust mixtures in the aircourse extending from 50 ft from its closed end to about 350 ft outby. The dust was distributed in the two entries and crosscuts, one-third on the floor, one-third on side shelves, and one-third on roof shelves. Pure coal dust was spread uniformly along the full length of the belt. The coal dust was either Pittsburgh pulverized coal containing about 80 pct of particles less than 74 μm in diameter and approximately 36 pct volatiles, or Pittsburgh mine-sized coal containing about 20 pct of particles less than 74 μm and similar in volatile content. The diameters of the rock dust particles and those of the pulverized coal dust were comparable.

The barrier consisted of one or two water-filled tubs of the German or modified-tub type mounted in a metal frame near the roof of the main entry at positions 200 to 350 ft from the face. Coal dust explosions were initiated by igniting the natural gas-air zone at the face, and the resultant gas explosion acted to pickup, disperse, and ignite the coal dust distributed in the mine, resulting in a propagating coal dust explosion.

EXPLOSIONS

Control Tests

Several gas explosion tests were conducted in the double entry to examine the response of the water tubs to double-entry explosions and to test a newly developed tub support assembly. Figure 3 shows two German tubs supported in such an assembly in the Experimental Mine. This barrier installation was used in all the suppression trials of this report, and is proposed for use in a barrier installation in a working mine. (See appendix.)

In previously reported barrier tests (3), water tubs were supported in a framework fixed permanently to the mine roof; the present barrier mounting was designed to simply hang from roof bolts for ease of installation in a working mine. The entire assembly is portable and can be rapidly installed and removed. Strong gas explosions were generated in the trials by igniting 30-ft-long, 8-pct natural gas-air mixtures at the face of the main entry. One or two German tubs were mounted in the main entry, 200, 300, or 350 ft from the face. In all the trials, the leading shock wave splintered the tub; the lowest shock pressure being 6 psi, which corresponds well with the minimum required pressure of 5 psi needed to rupture the tubs in previous single-entry tests using permanently fixed tub frames. Movies (taken with high-speed cameras positioned in the vicinity of the water tubs) showed that the water was well dispersed, and little motion or displacement of the supporting tub frame assembly occurred during the explosion.

Several control tests with coal dust in both entries without a belt or barrier were also conducted to delineate the response of the double-entry configuration to coal dust explosions. The gas ignition zone was 15 ft long and contained 7 pct natural gas. Pulverized coal-rock dust mixtures were spread in the main entry, crosscuts, and aircourse. The weight of the coal in the

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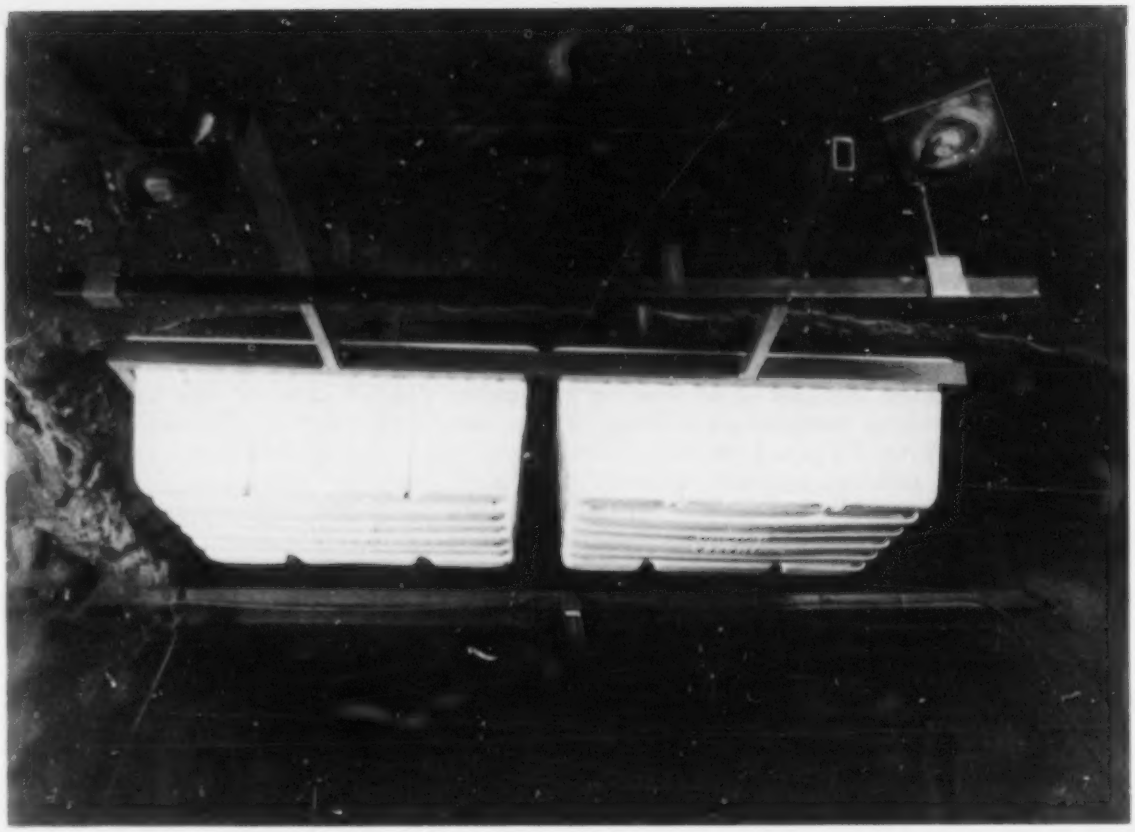


FIGURE 3. - Two German water tubs supported near roof.

mixture was sufficient to yield a concentration of 0.3 oz/ft^3 (nominal concentration) if dispersed uniformly through the mine volume occupied by a test zone. Main entry dust was kept in the flammable range (60 and 65 pct incombustibles) to simulate flammable conditions due to the coal on a belt in an operating mine; whereas, the aircourse dust was either nonflammable (75 pct incombustibles) or flammable, to represent conditions in an adjacent entry where rock dust content is or is not in compliance with the law.

Table 1 summarizes results of the control (C) tests.[4] Percent incombustible in the dust zones include rock dust and 8 pct ash in the coal. When both entries contained flammable dust mixtures (60 and 65 pct incombustibles, tests C-1 through C-3), flame and pressure development in the two entries was

[4]The tests in table 1 are referred to as C-1, C-2, etc. (and similar designations are used in all subsequent tables) to help the reader follow the text. Appendix table B-1 lists these test numbers and the corresponding test numbers as they appear in the author's test record book. The latter numbers should be used when querying the author regarding additional test details.

approximately equivalent. Figure 4 shows a wave diagram of explosion test C-1 in the main entry (fig. 4A) and aircourse (fig. 4B). These diagrams include time histories of flame arrival and static pressures. Pressures in both entries are observed to equalize at the speed of sound. When the level of incombustibles was raised to 75 pct in the aircourse of test C-4, flame speed, pressure development, and extent of flame propagation were again observed to be similar in both entries. This was surprising in view of the nonflammable test zone in the aircourse. Measurements of the progress of dust-cloud formation during coal dust explosions in the Experimental Mine have been reported previously (6), data of which indicate that dust on the mine surfaces is picked up shortly after passage of the pressure front preceding the flame (pioneer wave of fig. 4) and driven forward and dispersed over the mine cross section. Because of the time lapse between this pressure front and flame arrival (shown in fig. 4), considerable dust from the main entry can be ejected through the crosscuts into the aircourse ahead of the flame and act to propagate the explosion. This leads to the important conclusion that dust explosions in a belt entry of a coal mine can spread through crosscuts into adjacent rock-dusted entries and continue to propagate. However, the long distances traveled by the flame in the aircourse (test C-4) is difficult to explain on the basis of the quantity of main entry dust, which can be ejected into the aircourse through the three crosscuts, suggesting that at least the latter portion of aircourse flame travel may be supported by the flame in the main entry whose continued strong pressure fronts acts as a piston to drive forward the burning dust cloud in the aircourse. Since the duration of the luminous flame is 1 sec or longer (fig. 4), the flame sensors in the aircourse beyond 400 or 500 ft from the face may indeed be viewing the latter stages of burning of the dust as it is pushed ahead and not a self-sustaining propagation flame.

TABLE 1. - Summary of control coal dust explosions

Test	Test zones				Average flame speed,[4] ft/sec	Maximum pressure rise,[5] psi	Flame travel, ft (from face)
	Ignition[1]		Incombustibles, pct				
	Length, ft	Natural gas, pct	Main entry[2]	Air-course[3]			
C-1..	10	7	65	65	M,350 A,350	M,13 A,11	M,>650 A,>650
C-2..	10	7	65	65	M,310 A,130	M,6.5 A,5.5	M,>650 A, 550
C-3..	10	7.5	65	60	M,490 A,280	M,23 A,20	M,>650 A, 550
C-4..	15	8.5	65	75	M,350 A,230	M,9.5 A,6.5	M,>650 A,>700

[1]At face of main entry.
[2]Pittsburgh pulverized coal mixed with rock dust spread from 15 to 330 ft from face and in crosscuts.
[3]Pittsburgh pulverized coal mixed with rock dust spread from 50 to 330 ft.
[4]M = main entry; A = aircourse. Average flame speed 100 to 300 ft from face.
[5]Maximum pressure at 200 ft from face.

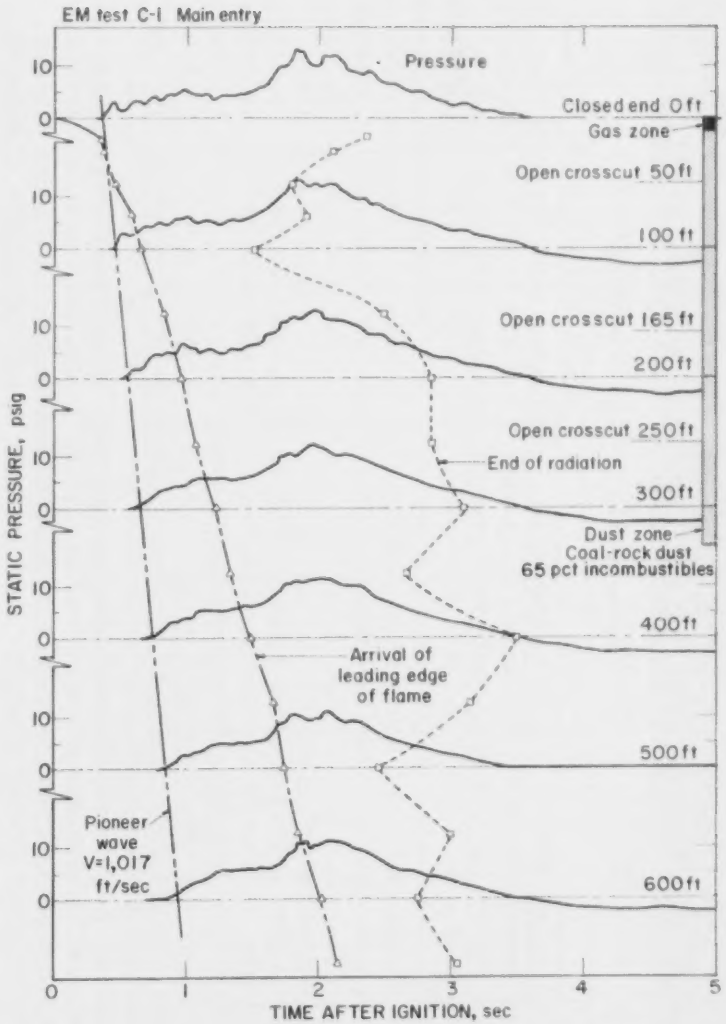


FIGURE 4. - Wave diagram of double-entry coal dust explosion. A, Test C-1, main entry.

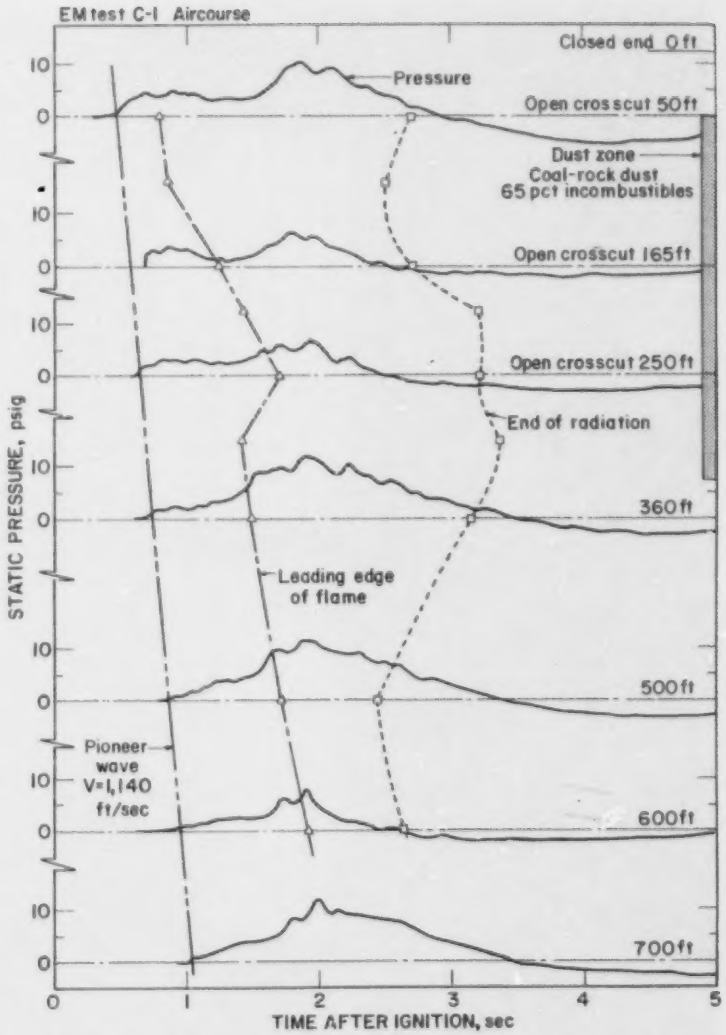


FIGURE 4. - Wave diagram of double-entry coal dust explosion. B, Test C-1, aircourse.

Simulated Belt

A beltway was simulated in the main entry in the next series of trials by the use of the 9-in-wide plastic strips. Dust mixtures spread in the double entry were similar to those used in test C-4: Pittsburgh pulverized coal mixed with rock dust containing 65 pct incombustibles in the main entry and crosscuts and nonflammable dust conditions in the adjacent entry (Pittsburgh pulverized coal plus rock dust containing 75 pct incombustibles); pure Pittsburgh pulverized coal was spread on the plastic strips. One or two water-filled German tubs were mounted near the roof of the main entry at positions of either 200 or 350 ft from the face.

Test conditions and results for all the simulated belt (SB) tests are summarized in table 2. In the first test (SB-1), pressures and flame speeds were a little higher than in test C-4 (similar test zones without a belt) even though the explosion was stopped early by the barrier, indicating the pure coal on the belt had some influence on the explosion intensity. It was also observed in this first test that the explosion was stopped in the aircourse at 300 ft thereby showing that little of the main entry dust is transferred through the 50- and 160-ft crosscuts. In test SB-2, one tub was sufficient to stop the explosion; however, the explosion intensity was somewhat weaker than in the control tests. An increase in the natural gas concentration of the ignition zone in test SB-3 served to increase the pressures and flame speeds, and one tub was still effective in stopping the explosion. The belt was raised to 4 ft from the floor and the natural gas concentration was decreased to 7 pct in test SB-4; the explosion was weak and the barrier was again successful. Moving the belt to cover the main entry from 250 to 350 ft from the face (test SB-5), and in addition, increasing the natural gas concentration (test SB-6), contributed little to the intensity of the explosion. In both tests, the barrier located at 350 ft failed to stop the explosion because it did not operate until well after passage of the flame (negative in the ΔT column). Failure of the tubs to respond is blamed on the drop in intensity of the pressure wave in passing the open 250-ft crosscut, which suggests that modified tubs (sensitive to low-wind forces) are necessary to stop explosions on beltways even during moderate-strength explosions, since stoppings cannot be expected to hold above several pressure differentials.

In the majority of the tests of this trial series, it seems that the belt dust contributed little to the explosion intensity. Yet, if dispersed alone, the belt dust would produce a flammable concentration of 0.075 to 0.100 oz/ft^3 in the mine volume of the belt zone. Whereas, if mixed with other dust, the effective incombustible in the belt zone would be of the order of 56 pct, a mixture that past experience indicates would result in a strong explosion (7). This suggest that (1) much of the belt dust is lost to the explosion by being dispersed prematurely, and (2) the plastic strips probably break free with the pioneer wave to free the entire belt dust immediately, which is then carried far ahead and diluted prior to being overtaken by the flame. Dust on the permanent side and roof shelves, however, is picked up gradually in back of the pioneer wave resulting in a progressive increase in dust concentration to reach a maximum immediately in front of the flame.

TABLE 2. - Summary of explosion suppression tests in simulated belt entry

Test	Test zones				Barrier[5]				Average flame speed,[6] ft/sec	Maximum pressure,[7] psi	Extent of flame travel, ft (from face)	Explosion suppressed
	Ignition,[1] percent natural gas	Incombustibles, pct		Belt[4]	Number of tubs	Distance from face, ft	Pressure at tub during operation, psi	ΔT, sec				
		Main entry[2]	Air-course[3]									
SB-1	7	65	75	B	2	200	7	0.20	M,550 A,180	M,10 A,10	M,200 A,300	Yes. Yes.
SB-2	>7	65	75	C	1	200	5	.38	M,350 A,120	M,7 A,7	M,250 A,100	Yes. Yes.
SB-3	8	65	75	C	1	200	8	.18	M,500 A,130	M,13 A,10	M,200 A,300	Yes. Yes.
SB-4	7	65	75	D	1	200	5	.26	M,400 A,100	M,8 A,8	M,200 A,250	Yes. Yes.
SB-5	7	65	75	E	1	350	NM	-.4	M,280 A,150	M,7 A,5	M,550 A,300	No. Yes.
SB-6	8.5	65	75	E	1	350	NM	-.3	M,300 A,170	M,8 NM	M,550 A,360	No. Yes.

NM Not measured.

[1]At face of main entry, 15 ft long.

[2]Pittsburgh pulverized coal mixed with rock dust, spread from 15 to 330 ft from face and in crosscuts.

[3]Pittsburgh pulverized coal mixed with rock dust, spread from 50 to 330 ft.

[4]9-in-wide plastic belt in main entry. B = belt 2 ft from floor extending 50 to 165 ft from face, pure Pittsburgh pulverized coal spread on belt at rate of 1/4 lb per linear foot of belt. C = belt 2 ft from floor 50 to 165 and 250 to 300 foot from face, pure Pittsburgh pulverized coal spread on belt at rate of 1/3 lb per linear foot of belt. D = belt 4 ft from floor 50 to 165 ft from face, pure Pittsburgh pulverized coal spread on belt at rate of 1/3 lb per linear foot of belt. E = belt 2 ft from floor 250 to 350 ft from face, pure Pittsburgh pulverized coal spread on belt at rate of 1/3 lb per linear foot of belt.

[6]M = main entry; A = aircourse. Average flame speed 100 to 300 ft from face.

[7]Maximum static pressure at 200 ft from face.

Conveyor Belt

Pulverized Coal

The conveyor belt system represents the conventional method of transporting coal from the coal face. The conveyor belt used in the tests was 2 ft wide by 2 ft high by 200 ft long and was bolted to the floor in the main entry. The same coal-rock dust mixtures were spread in the main entry and aircourse in this test series as in the previous series. In the initial conveyor belt tests using pulverized coal (CBP), the belt was located between 100 and 300 ft from the face. The first two tests (CBP-1 and CBP-2) of table 3 were control trials with no dust on the belt; flame speeds, pressures, and extent of flame travel were similar to a previous control run (test C-4) with no belt, indicating that the belt conveyor caused little change in the characteristics of the explosion. In test CBP-3, the coal was spread on the belt at the rate of one-third pound per linear foot, and a much stronger explosion developed, which illustrates that the belt dust was now a conducive factor. Three dust probes mounted near the belt surface at various distances along the belt length showed that the dust lifted behind the pressure front at approximately the same time as the lifting of roof and side-shelve dust, with dust concentration reaching a maximum immediately in front of the flame. However, belt motion did occur during the explosion. Inspection following the explosions showed that the belt pulled off the rollers and was lying alongside the conveyor frame. Initial conditions for test CBP-4 were unchanged except for two German water tubs mounted in the main entry at 200 ft from the face. Good suppression was obtained, and flame speed and pressures were less than those of the previous trial owing to early arrest of the explosion. The two German tubs were shifted to 300 ft from the face in test CBP-5 with all other conditions unchanged. The explosion was not suppressed owing to late operation of the tubs ($\Delta T \approx 0.07$ and 0.09 sec). As observed in a similar previous test with the plastic belt (tests SB-5 and SB-6, table 2), the poor barrier operation is due to the drop in dynamic pressure as the pressure wave passes the open 250-ft crosscut. Replacing the barrier with modified tubs (low-pressure sensitive, test CBP- 6) near the same mine location resulted in a suppression in the main entry (flame stopped at 450 ft), and a nonsuppression in the aircourse (flame propagating beyond the last flame sensor). This showed again the strong influence of the 250-ft crosscut to the transport of dust into the aircourse. In addition, examination of the results of test CBP-6 indicated that the flame in the main entry arrived at the 450-ft station at approximately 0.2 sec after the aircourse flame passed the 700-ft station, which shows that the long flame travel in the aircourse was probably due to the pressures developed by the main entry flame. In the last two tests, the belt was moved outby to extend from 200 to 400 ft from the face, and dry cement block (8-inch hollow block) stoppings were placed in the 250-ft crosscut. Two German tubs were again placed at the 300-ft location. The purpose of the stoppings was to make mine conditions more realistic, and to determine if the integrity of the stopping would be maintained for a sufficient time to slow down the dust transfer through the crosscuts and sustain the pressure wave intensity required to operate the German tub. Thin wires were placed across the intersection of two blocks at 10 equidistant locations across the face of the stoppings. Signals transmitted during the breaking of each wire indicated the time that section of wall was being destroyed. In both tests (CBP-7 and CBP-8), the German tubs were successful in suppressing the explosion. Figure 5 is a photograph of the stopping for test CBP-7 prior to and after the test as viewed from the side of the aircourse entry; figure 6 is a wave diagram illustrating the results of the test in the main entry. Destruction of the stopping is observed to begin approximately 0.1 sec after the pressure wave reaches about 5 psi; the stopping is completely destroyed in an additional 0.3 sec. Pressure decay by the 250-ft crosscut was delayed for sufficient time for the tubs to operate at the time well before arrival of the flame. Delay in destruction of the stopping was also responsible for little dust transfer into the aircourse, as witnessed by flame stoppage at 300 ft in the aircourse.

TABLE 3. - Summary of explosion suppression tests in conveyor belt entry using Pittsburgh pulverized coal

Test	Test zones				Barrier[5]				Average flame speed,[6] ft/sec	Maximum pressure,[7] psi	Extent of flame travel, ft (from face)	Explosion suppressed
	Ignition,[1] percent natural gas	Incombustibles, pct		Belt[4]	Number and type of tubs	Distance from face, ft	Pressure at tubs during operation, psi	ΔT, sec				
		Main entry[2]	Air-course[3]									
CBP-1	8.5	65	75	F	None	NAp	NAp	NAp	M,370 A,210	M,10 A,9	M,>650 A,>700	No. No.
CBP-2	8.5	65	75	F	None	NAp	NAp	NAp	M,310 A,240	M,8 A,8	M,>650 A,>700	No. No.
CBP-3	8.0	65	75	H	None	NAp	NAp	NAp	M,670 A,300	M,19 A,17	M,>650 A,>700	No. No.
CBP-4	8.0	65	75	H	2G	200	6, 6	0.16,0.20	M,500 A,370	M,13 A,13	M, 200 A, 350	Yes. Yes.
CBP-5	8.0	65	75	H	2G	300	5, 10	0.07,0.09	M,770 A,690	M,19 A,20	M,>650 A,>700	No. No.
CBP-6	8	65	75	H	2M	315	3, 2.5	0.32,0.32	M,720 A,500	M,19 A,18	M, 450 A,>700	Yes. No.
CBP-7[8]	8	65	75	I	2G	300	5, 5	0.39,0.38	M,420 A,280	M,10 A,9	M, 300 A, 300	Yes. Yes.
CBP-8[8]	7	65	75	I	2G	300	4, 4	0.61,0.60	M,250 A,200	M,6 A,5	M, 300 A, 300	Yes. Yes.

NAp Not applicable.

[1]At face of main entry, 15 ft long.

[2]Pittsburgh pulverized coal mixed with rock dust, spread from 15 to 330 ft from face and in crosscuts.

[3]Pittsburgh pulverized coal mixed with rock dust, spread from 50 to 330 ft.

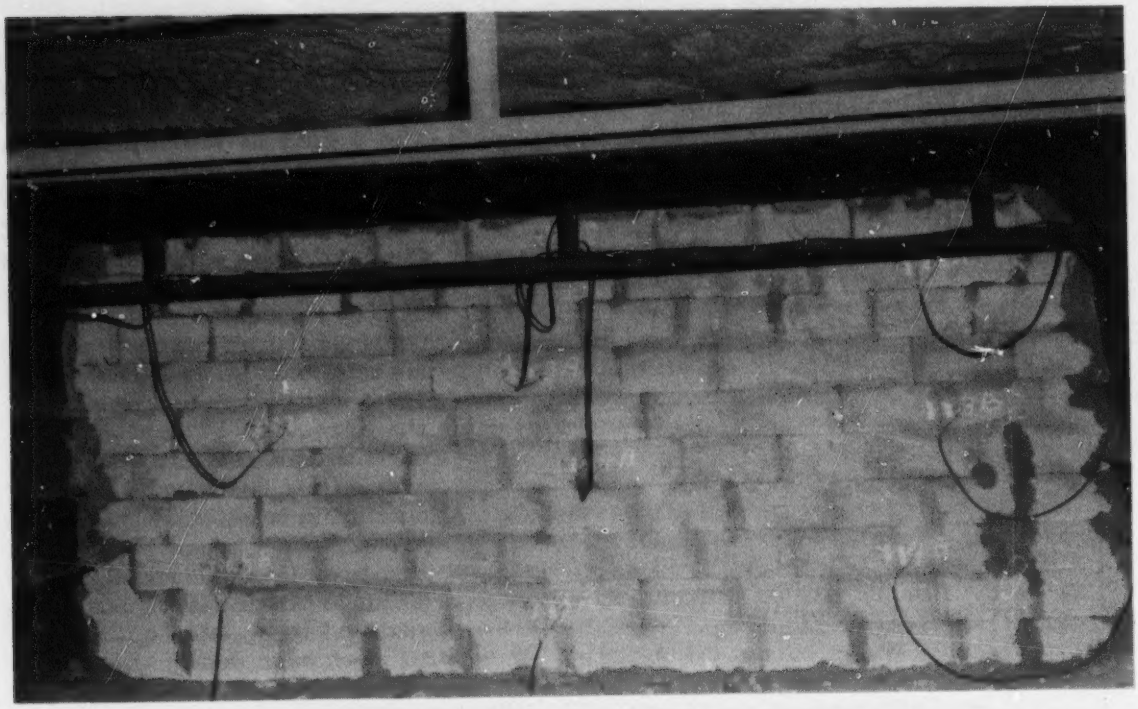
[4]2-ft-wide conveyor belt in main entry. F = belt 100 to 300 ft from face, no dust; H = belt 100 to 300 ft from face, pure Pittsburgh pulverized coal spread on belt at rate of 1/3 lb per linear foot; I = belt 200 to 400 ft from face, pure Pittsburgh pulverized coal spread on belt at rate of 1/3 lb per linear foot.

[5]Barrier in main entry. G, German tub; M, modified tub. ΔT, time interval from tub operation to flame arrival at barrier.

[6]M = main entry; A = aircourse. Average flame speed 100 to 300 ft from face.

[7]Maximum static pressure at 200 ft from face.

[8]Cement block stoppings in crosscut at 250 ft.



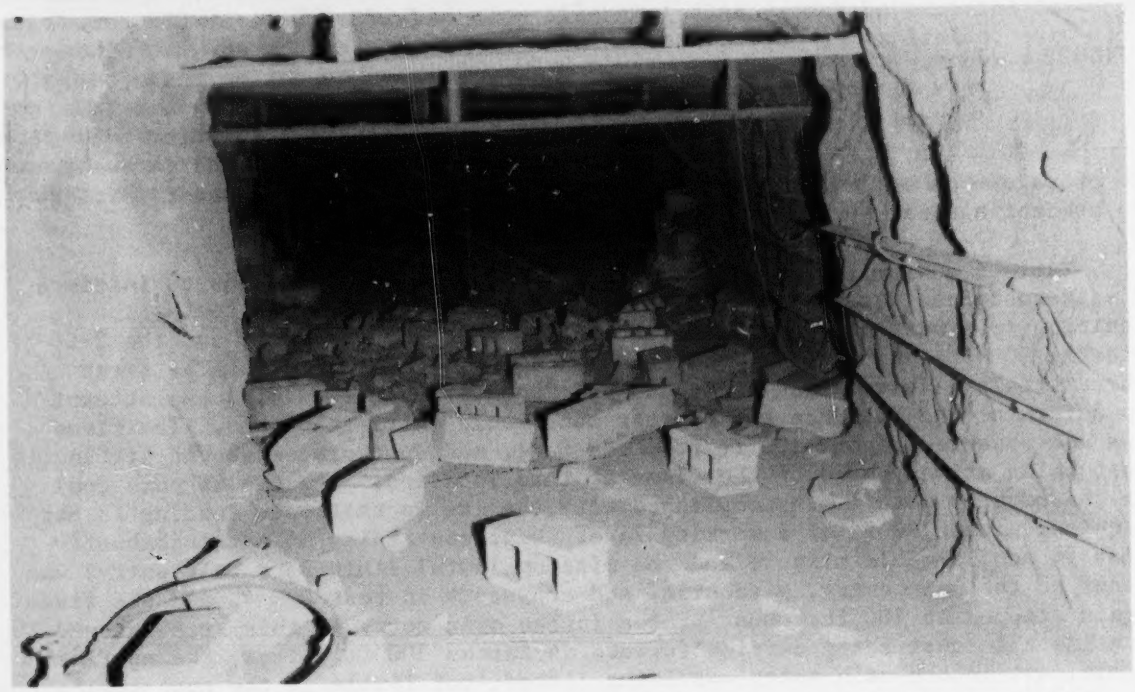


FIGURE 5. - Photograph of cement block stopping in 250-ft crosscut of the Experimental Mine. Closeup view prior to explosion (top); far-field view after explosion (bottom).

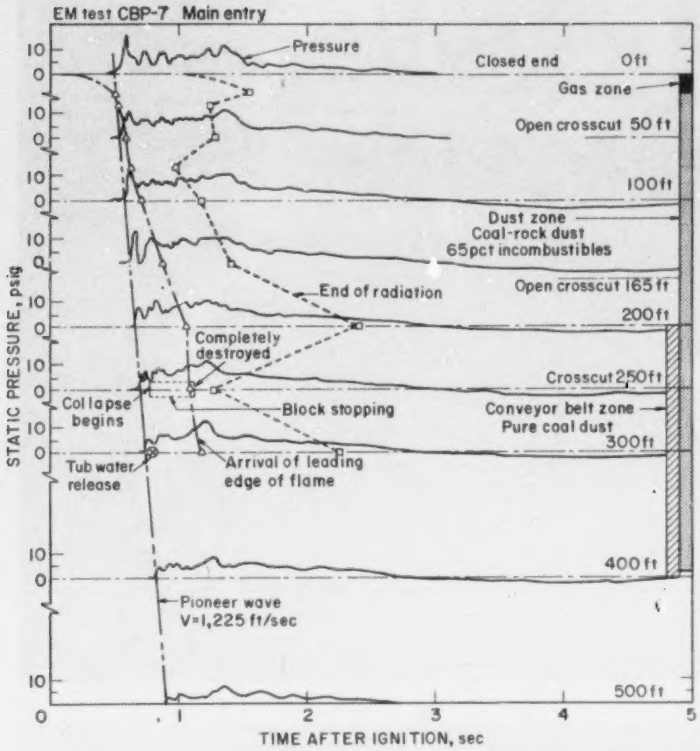


FIGURE 6. - Wave diagram of a coal dust explosion in the main entry illustrating the results of test CBP-7 using a cement block stopping at the 250-ft crosscut.

Mine-Size Coal

The final objective of this study was to determine the degree to which a conveyor beltway poses a potential explosion hazard in an operating mine rock dusted in compliance with regulations. In the previous trial, it was convenient to use Pittsburgh pulverized coal because of the ease of initiating and controlling the intensity of explosions with this material. However, in a beltway of an operating mine, the coal particles that can become involved in and contribute to an explosion are considerably larger and equivalent to coal dust designated as mine-size coal. Therefore, a limited number of trials (referred to as CBM tests) were conducted with mine-size to define those coal conditions along a beltway that are realistic to a working mine and necessary to propagate an explosion, and in addition assess the value of water barriers to protect against such explosions.

Table 4 summarizes results of the trials in which conditions to initiate a self-sustaining explosion were determined. Similar to prior tests, the ignition zone was located at the face region of the main entry, and the 2-ft-wide by 200-ft-long conveyor belt started 100 ft from the face. The first three trials involved the "ignition" and "booster" zones only, in an attempt to determine the distance the booster zone would carry the flame. The flame was not observed beyond 100 ft from the face, and dust probes showed little dust being driven ahead of the flame at this location. The use of pure coal in the booster zone is in compliance with the law in that rock dusting is not required within 50 ft of a working face. Dust containing 65 pct incombustibles (a nonflammable mixture and the minimum lawful limit in a belt entry) was added to the main entry, aircourse, and crosscuts in test CBM-4, and the flame again stopped at 100 ft. Dust probes in the main entry in this trial showed considerable dust being carried forward as far as 300 ft. Thus, the nonflammable dust in the main entry was being lifted, but little of the pure coal of the booster zone was penetrating beyond 100 ft. The longer ignition zone of test CBM-5 was observed to force somewhat more booster zone dust past 100 ft;

however, the extent of the flame travel was unchanged. Continuing with the stronger ignition and adding dust to the main entry and belt (test CBM-6) extended the flame to 150 ft. A new zone (runup zone) in the next trial (test CBM-7) pushed the flame to 200 ft. Finally, a self-generating explosion was attained in test CBM-8 by decreasing the percent of incombustibles in the runup zone and increasing the quantity of coal on the belt. Test CBM-9 proved that the belt dust is a necessary ingredient for a self-sustaining explosion. The runup zone in these trials is not typical in a properly rock-dusted mine. However, there is little doubt that this zone can be eliminated and a self-generating explosion obtained by increasing the ignition strength (increase the percent of natural gas) and raising the booster zone coal to 2 lb/ft or more. The resulting increase in explosion intensity with its accompanying high noise level, however, could not be tolerated at the Bruceton facility because of complaints from neighboring areas.

The 1.5 lb/ft of mine-size coal spread on the belt is representative of the quantity found in the run-of-mine coal on a 2-ft-wide loaded belt in an operating mine. Previous studies have shown that approximately 7.5 pct of Pittsburgh run-of-mine coal is in the mine-size-coal range (1, 8). A 2-ft-wide belt has a coal-carrying capacity of about 20 lb/ft (5), which would yield about 1.5 lb/ft of mine-size coal; comparable to the quantity used in this study. On the other hand, a 4-ft-wide belt commonly used in an 18-ft-wide entry has a capacity of about 80 lb/ft, which would yield approximately 6 lb/ft of mine-size coal. The concentration of this dust in an 18-ft-wide by 6-ft-high entry when dispersed would be two times greater than in our experiments. Since all the fine mine-size coal dust cannot be expected to separate from the larger coal in run-of-mine coal during an explosion, our usage of 1.5 lb of mine-size coal per foot of belt is not a valid estimate of conditions in a 9-ft-wide entry (width of the Experimental Mine). However, most U.S. mines are of the order of 18 ft wide; therefore the present experiment would be valid for such entries assuming that at least 50 pct of the fine dust in the run-of-mine coal is freed to be available to the explosion.

TABLE 4. - Summary of explosion tests in conveyor belt entry using mine-size coal

Test	Test zones[1]														Flame travel, ft (from face)
	Ignition[2]		Booster[3]		Runup[4]			Main entry			Aircourse[5]			Belt[6]	
	Length, ft	Natural gas, pct	Length, ft	Quantity of coal, lb/ft	Length, ft	Quantity of coal, lb/ft	Incombustibles, pct	Length, ft	Quantity of coal, lb/ft	Incombustibles, pct	Length, ft	Quantity of coal, lb/ft	Incombustibles, pct		
CBM-1	15	7	M,15-M,50	0.84	No dust...	None	NAp	No dust	None	NAp	No dust	None	NAp	No dust	M,100 A,0
CBM-2	15	7	M,15-M,50	1.14	...do.....	None	NAp	..do...	None	NAp	..do...	None	NAp	..do...	M,100 A,0
CBM-3	15	8.5	M,15-M,50	1.14	...do.....	None	NAp	..do...	None	NAp	..do...	None	NAp	..do...	M,100 A,0
CBM-4	15	8.5	M,15-M,50	1.14	...do.....	None	NAp	50-350	1.0	65	50-350	1.0	65	..do...	M,100 A,50
CBM-5	40	6.5	M,15-M,50	1.5	...do.....	None	NAp	No dust	None	NAp	No dust	None	NAp	..do...	M,100 A,0
CBM-6	40	6.5	M,15-M,50	1.5	...do.....	None	NAp	50-250	.5	65	..do...	None	NAp	J	M,150 A,0
CBM-7	40	6.5	M,15-M,50	1.5	M,50-M,100	1.0	45	100-300	.5	65	..do...	None	NAp	J	M,200 A,0
CBM-8	40	6.5	M,15-M,50	1.5	M,50-M,100	1.0	40	100-300	.5	65	..do...	None	NAp	K	M,>650 A,50
CBM-9	40	6.5	M,15-M,50	1.5	M,50-M,100	1.0	40	100-300	.5	65	50-350	.5	65	No dust	M,100 A,100

NAp Not applicable.
[1]M = main entry; A = aircourse. Pittsburgh mine-size coal in all dust zones.
[2]Length from face in main entry.
[3]Pure mine-size coal. Quantity of coal in pounds per linear foot of entry.
[4]Incombustibles include rock dust and 8 pct ash in coal.
[5]Same dust mixture as in crosscuts.
[6]2-ft-wide conveyor belt, 100 to 300 from face in main entry. J = pure mine-size coal spread at rate of 1/2 lb per linear foot of belt; K = pure mine-size coal spread at rate of 1.5 lb per linear foot of belt.

Serious thought had been given to using run-of-mine coal in the experiments rather than the mine-size coal to simulate more closely conditions in an operating mine. However, fine dust can be easily lifted from a stationary surface by the explosion wind force; whereas, the larger run-of-mine coal would require the additional motion of the surface (belt) to be readily suspended. Therefore, because of the unpredictable motion of the belt during an explosion and therefore the variability in the percent of fine coal dust released from the larger coal, trials using run-of-mine coal would not be reproducible.

Test zones for the barrier suppression trials (table 5) were similar to the successful explosion test CBM-9 of the previous table with aircourse dust added. In the first trial of table 5, the drop in barrier efficiency is due to the long time interval of 0.9 sec between water release and flame arrival. In the following three trials, the single tub located 200 ft from the face was sufficient to stop the explosion. The value of increasing the rock dust concentration along a belt entry to control the explosion hazard was examined in the last trial by raising the incombustible content in the main entry test zone to 80 pct. Explosion intensity was reduced, but the flame still propagated for some distance. Assuming that the main entry and belt dust mixed well during the explosion the result would be an effective incombustibles level of 52 pct, which is well beyond the 45 pct incombustibles required to inert mine-size coal (6). Good mixing, therefore, does not occur, and increasing the rock dust content along a belt roadway is not a completely adequate means of eliminating the explosion hazard.

TABLE 5. - Summary of explosion suppression tests in conveyor belt entry using mine-size coal

Test No.	Test zones						Barrier[7]				Average flame speed,[8] ft/sec	Maximum pressure,[9] psi	Flame travel, ft (from face)	Explosion suppressed
	Ignition,[1] percent natural gas	Incombustibles, pct					Number and type of tub	Distance from face, ft	Pressure at tub during operation, psi	ΔT, sec				
		Booster[2]	Run-up[3]	Main entry[4]	Air-course[5]	Belt[6]								
CBM-10	6.5	8	40	65	65	L	1 M 1 G	300 300	3 5	0.9 1.0	M,190 A,110	M,7.5 A,6	M,550 A,250	Marginally. Yes.
CBM-11	6.5	8	40	65	65	L	1 G 1 G	200 300	7	.5	M,200	M,6.5 A,5	M,200 A,50	Yes. Yes.
CBM-12	6.5	8	40	65	65	L	1 G 1 G	200 300	7	.4	M,230 A,90	M,7.5 A,6	M,250 A,165	Yes. Yes.
CBM-13	6.5	8	40	65	65	L	1 G 1 G	200 300	12	.4	M,260 A,70	M,7 A,6	M,200 A,200	Yes. Yes.
CBM-14	7.0	8	40	80	65	L	None	NAp	NAp	NAp	M,90 A,90	M,6 A,6	M,500 A,200	Marginally. Yes.

NAp Not applicable.

[1]At face of entry, 40 ft long.

[2]Pure mine-size coal spread in main entry from 15 to 50 ft from face at rate of 1.5 lb per linear foot of entry.

[3]Mine-size coal mixed with rock dust spread in main entry from 50 to 100 ft from face at rate of 1 lb coal per linear foot of entry.

[4]Mine-size coal mixed with rock dust spread from 100 to 300 ft from face at rate of 0.5 lb coal per linear foot of entry.

[5]Mine-size coal mixed with rock dust spread from 50 to 300 ft from face and in crosscuts at rate of 0.5 lb coal per linear foot of entry.

[6]2-ft-wide conveyor belt in main entry, 100 to 300 ft from face. L = pure mine-size coal spread at rate of 1.5 lb per linear foot of belt.

[7]Barrier in main entry. M = modified tub; G = German tub. ΔT, time interval from tub operation to flame arrival at barrier.

[8]M = main entry; A = aircourse. Average flame speed 100 to 300 ft from face.

[9]Maximum static pressure at 200 ft from face.

WATER BARRIERS IN WORKING MINES

On the basis of past and present Bureau experimentation with water barriers and the knowledge gained from researchers abroad on a variety of water barriers and mine geometries, tentative plans can be made for the use of water barriers in U.S. coal mines.

The West Germans have found the PVC water tubs satisfactory for stopping moderate-strength coal dust explosions. Regulations (2) for the use of these tubs in West German coal mines can be summarized as follows:

In long wall mining, the water barriers on conveyor roads shall be located at least 50 yd and not more than 120 yd from the working face; in room-and-pillar workings, the barrier on conveyor roads shall be at least 150 yd and not more than 400 yd from the working face. The barriers shall be rigidly held in support frames in the upper third of the roadway with the tubs longside at right angles to the road axis. Total distance between barriers and ribs shall not exceed 5 ft. At least 35 pct of the roadway width should be covered by barriers for mine cross sections up to 108 ft^2, at least 50 pct up to 162 ft^2, and at least 65 pct over 162 ft^2. Total quantity of water in a barrier system shall be at least 4.5 gal/ft^2 of road cross section and at least 0.03 gal/ft^3 of road volume (width of cross section times length of barrier system). The barrier system shall be at least 22 yd long.

Other European countries have tested passive water barriers and found them effective in extinguishing moderate-strength explosions. Tests also indicate that the minimum quantity of water in the barrier should be at least 4.5 gal/ft^2.

The West German water barrier regulations refer to concentrated barriers--water tub rows grouped close together (rows 10 to 20 ft apart) resulting in a short barrier-system length. Such barriers can be ineffective when an explosion is initiated close to or far from the barrier. In the former case, the explosion may not have time to develop sufficient force to upset or fragment the tubs, or the time before flame arrival at the barrier may not be adequate for the water to disperse and fill the entry cross section. Whereas, in the latter case, the blast wave preceding the flame may disperse the water prematurely. In addition, the study described in the present report indicates that a concentrated barrier would not be satisfactory on a beltway, and that the explosion may propagate into adjacent entries prior to meeting the barrier and then reenter the beltway ahead of the barrier to continue to propagate unhindered.

Distributed barriers have also been studied overseas. In this system, the distance between rows of water containers is increased to 50 to over 100 ft, and the total barrier can be lengthened to thousands of feet. This increases the probability that a portion of the system will be at some optimum distance from the explosion source. On a beltway, the distributed barrier will minimize the potential of flame spread into adjacent entries or flame reentering the beltway. In overseas work with distributed barriers, as little as 0.23 gal/ft^2 of mine cross section per row of water tubs, with rows greater

than 60 ft apart, was successful in arresting explosions propagating at speeds up to 1,200 ft/sec. In earlier work in the single entry of the Experimental Mine, a single German tub yielding a water density of 0.33 gal/ft^2 of mine cross section was adequate to stop explosion propagation at speeds of 250 to over 1,000 ft/sec. This single tub occupied less than 30 pct of the road width, and no change in efficiency was noted for the tub placed near the rib or near the center of the roadway. In similar tests, single modified tubs (sensitive to low pressures) were also successful in suppressing weak dust explosions propagating at speeds as low as 100 ft/sec. Tests performed for this report confirms that these water tubs can operate equally well on a beltway.

PROPOSED BARRIER ON BELTWAY

The distributed passive water barrier is proposed as the most practical system for protecting belt conveyor roadways in U.S. mines. The barrier should consist of a number of rows of water-filled tubs including both the German tub and the modified tub shown in figures 1 and 2 and described in the appendix of this report. This would offer protection against weak to moderate-strength explosions. The barrier should begin just outby the loading region of the belt and consist of as many rows as practical, each row to contain approximately equal numbers of German and modified tubs. A row is identified as a number of tubs extending across the entry from rib to rib.

Each row should be one crosscut apart and near the center between two crosscuts. The tubs should be mounted near the mine roof with their long sides at right angles to the road axis. The tubs in each row should occupy at least 50 pct of the roadway width when the road height is greater than 20 pct of the width, and at least 67 pct of the road width when the height is less than 20 pct of the width. The spacing between the barriers and the distance of barrier to rib should be uniform if possible. Where it is impractical to mount the tub row in a straight line, tubs can be staggered to a maximum of 10 ft from the front to rear tub, but the distance betweeen tubs as measured along a straight line from rib to rib should be uniform if possible. If there is insufficient clearance above the belt, the tubs can be erected on each side of the belt. Each row of tubs should hold a quantity of water equal to at least 0.65 gal/ft^2 of road cross section and equal to at least 0.008 gal/ft^3 of the mine volume between two rows. To insure adequate protection in low coal roads, the ratio of road height to width should be the cardinal criterion for choosing the number of tubs in a row. For example, from the preceding recommendation, an entry of 5 ft high by 18 ft wide and 90 ft between crosscuts would result in a 50-pct road width coverage by tubs. This would necessitate four barriers (each about 32 in long), which would yield approximately 1 gal of water per square foot of cross section or 0.01 gal/ft^2 of mine volume between rows.

The appendix of this report describes the German and modified tubs to be used on beltways and details of their mounting assemblies.

CONCLUSIONS

This study indicates that a coal dust explosion can be readily initiated in a conveyor belt entry using conditions that simulate that of an operating mine. In addition, coal dust from the beltway can be ejected ahead of the flame through opened crosscuts (stoppings destroyed by explosion) into adjacent entries to propagate the explosion for long distances even though the adjacent entries are rock dusted in compliance with regulations.

Passive water barriers (water-filled tubs) can be used successfully to stop explosions on a beltway; however, the barrier efficiency decreases when the time between barrier operation (water release) and flame arrival at the barrier site is less than 0.1 sec or greater than about 1.0 sec.

Barrier effectiveness may also be reduced by opened crosscuts during moderate or weak explosions. This occurs because of a drop in intensity of the pressure wave preceding the flame in passing the crosscut, to a level insufficient to operate the barrier. Modified tubs (sensitive to low pressures) should therefore be included in the barrier installation on a beltway.

Extinguishing an explosion in a belt entry will not necessarily stop the spread of the explosion into adjacent entries through opened crosscuts preceding the site of explosion suppression. Therefore, crosscut stoppings should be strong and heavy to maintain their integrity during the explosion as long as possible to minimize coal dust transport.

Passive water barriers on a beltway should be the distributed type; that is, they should consist of a row of water-filled tubs between each of two crosscuts, the rows to continue unbroken for long distances along the entry. This configuration (1) will increase the probability that a portion of the barrier system will be at some optimum distance from the explosion source to offer the most favorable chances of suppressing the explosion, (2) assure that coal dust from the beltway pushed ahead of the flame through opened stoppings is inerted with water, thus minimizing the probability of flame spread into adjacent entries, and (3) reduce the possibility that the explosion will proceed down the second entry and return to the first entry and continue the explosion.

REFERENCES

1. Cheng, L., and P. O. Zukovich. Respirable Dust Adhering to Run-of-Face Bituminous Coals. BuMines RI 7765, 1973, 10 pp.

2. Germany, Federal Republic of, Department of Mines. Coal Mines Regulations, October 1912, as Amended. Location, Installation, and Maintenance of Water Barriers. Sec. 54, General Rule 12B, (14) (a), papers M68/1773, Apr. 11, 1968.

3. Liebman, I., J. Corry, and J. K. Richmond. Water Barriers for Suppressing Coal Dust Explosions. BuMines RI 8170, 1976, 26 pp.

4. Liebman, I., and J. K. Richmond. Suppression of Coal Dust Explosions by Passive Water Barriers in a Single-Entry Mine. BuMines RI 7815, 1974, 34 pp.

5. Meador, W. E. Underground Conveyors for Main-Line and Secondary Haulage. SME Mining Engineering Handbook. SME, American Institute of Mining, Metallurgical, and Petroleum Engineers Inc., New York, v. 1, sec. 14.3, 1973, pp. 19-23.

6. Richmond, J. K., I. Liebman, A. E. Bruszak, and L. F. Miller. A Physical Description of Coal Mine Explosions, Part II. 17th Internat. Symp. on Combustion. The Combustion Institute, Pittsburgh, Pa., 1979, pp. 1257-1267.

7. Richmond, J. K., I. Liebman, and L. F. Miller. Effect of Rock Dust on Explosibility of Coal Dust. BuMines RI 8077, 1975, 34 pp.

8. Winegartner, E. C. Rosin-Rammler Charts and Their Application to Size Distribution Problems. Proc. Bulk Materials Handling Seminar, Univ. of Pittsburgh, Pittsburgh, Pa., v. 5, December 1977, 17 pp.

APPENDIX A.--BARRIER INSTALLATION FOR A WORKING MINE

Figure 1 at the beginning of this report shows photographs of the German and modified tubs proposed for use in the water barrier installation on the beltway. Figure A-1 gives the tub dimensions. For convenience the modified tub is made from the German tub, and is altered by simply removing the side lip supports and beveling the front and rear lip support. The German tub is supported rigidly by means of its total upper lip surface resting on a metal frame; the wind force fractures the tub walls as the tub is pushed out of the frame to release the water. Only the front and rear lips of the modified tub support rests on the metal frame; the wind force drives the face and supporting lip of the tub inward and the tub falls pivoting about its rear lip, which is forced against the metal frame to spill its water. With this novel lip support, the modified tub can operate at wind speeds as low as 100 ft/sec and thereby is effective in suppressing slow-moving coal dust explosions.

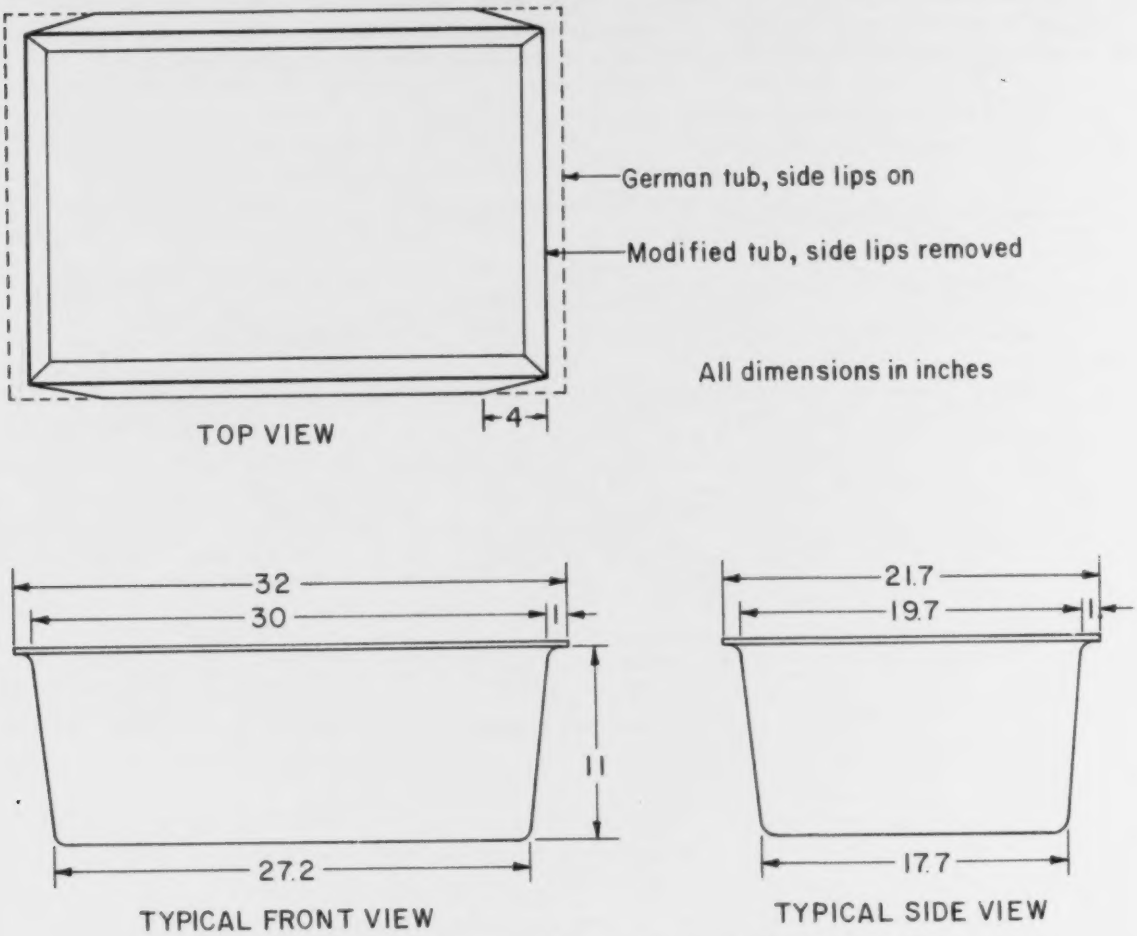


FIGURE A-1. - Dimensions of German and modified water tubs.

Figures A-2 and A-3 illustrate plans for a one- and two-tub assembly. Four roof bolt plates, spaced at the corners of an approximate 4-ft square, are used to hang each metal frame assembly. The roof-bolt plates must contain hanger holes. The metal frames are made of rectangular carbon steel tubing; however, other structural shapes or material can be used. The tub space allotted in the frames will fit either the German or modified tubs or a combination of the two in the case of the two-tub assembly. To mount a one- or two-tub assembly, four hanger hooks are first suspended from roof-bolt plate holes. The length of the hanger hooks will vary (4 to 10 in) depending on the level uniformity of the roof, and suitable length should be chosen in order that the sleeves will hang at the same (within 2 in) horizontal level. Two frame supports are then inserted into the appropriate hanger sleeves so as to be at right angles to the road axis. The empty tubs are placed in the metal frame, which is slid into position over the frame supports. Frame clamps are then fastened and the tubs filled with water and covered with lids. (There should be at least 2 in. between the tub rim and mine roof for water filling.) As the section advances, new rows of tubs will be erected. Each row should contain a nearly equal number of German and modified tubs. When tubs need to be removed, aspiration techniques should be used for water drainage.

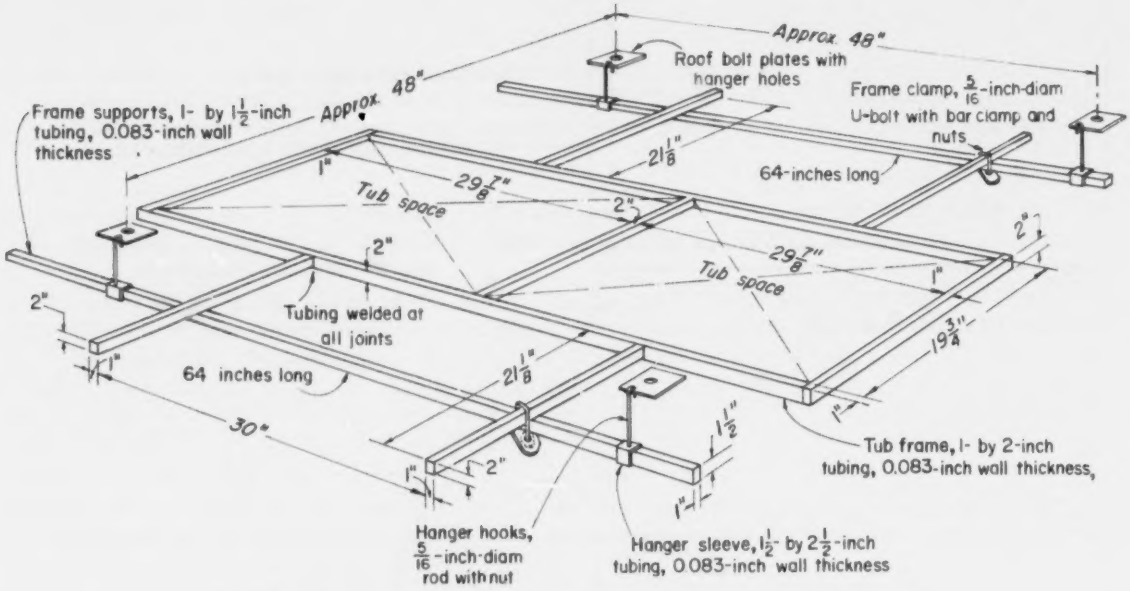


FIGURE A-2. - Plan of water tub support assembly for one tub.

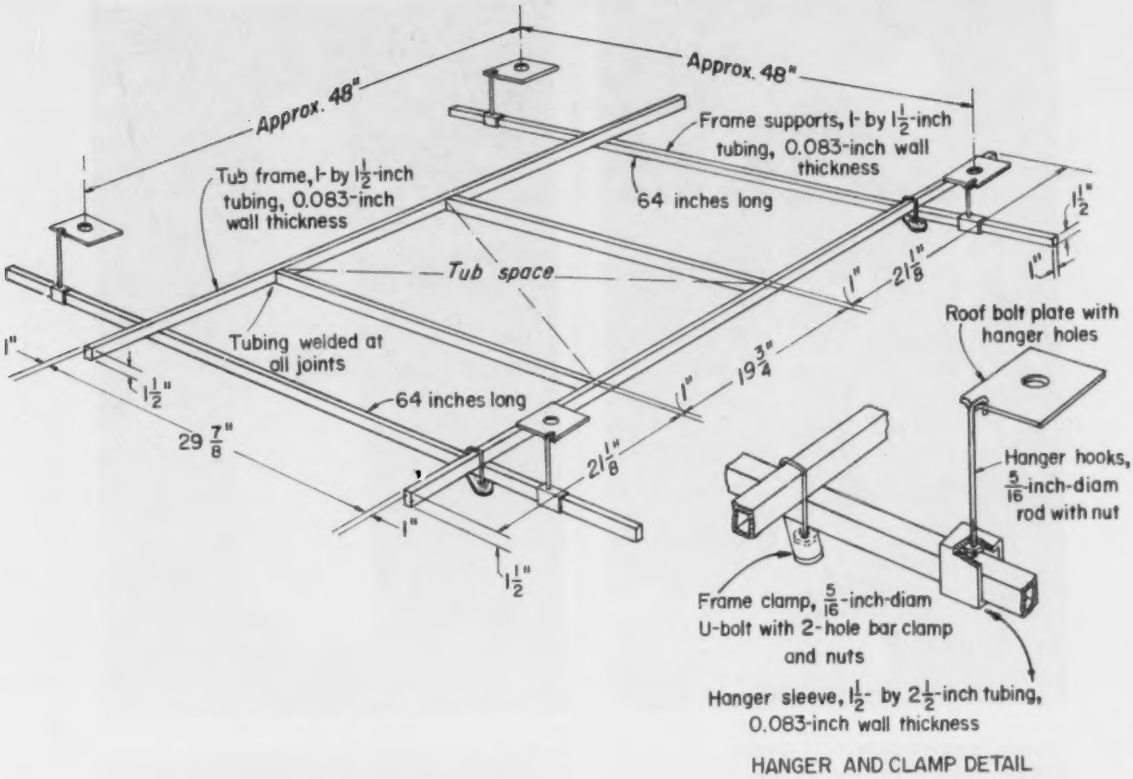


FIGURE A-3. - Plan of water tub support assembly for two tubs.

Figure A-4 shows the mounting sequence of a two-tub assembly in the Experimental Mine.

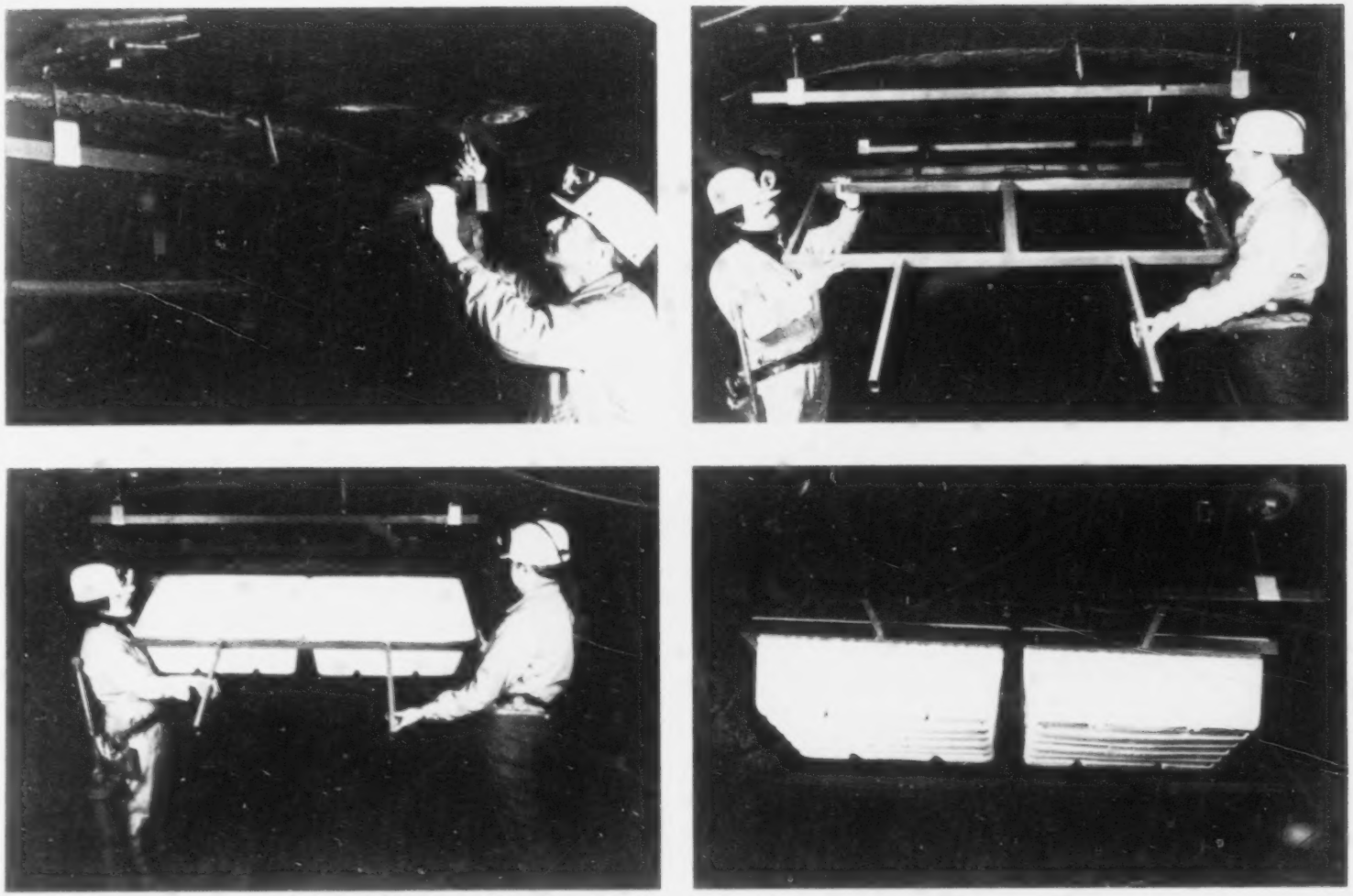


FIGURE A-4. - Mounting sequence of a two-tub assembly.

APPENDIX B.--CROSS-REFERENCE FOR TEST NUMBERS

This manuscript	Test record book	This manuscript	Test record book
C-1	3748	CBM-1	3783
C-2	3749	CBM-2	3784
C-3	3750	CBM-3	3785
C-4	3765	CBM-4	3786
		CBM-5	3787
SB-1	3755	CBM-6	3788
SB-2	3756	CBM-7	3789
SB-3	3758		
SB-4	3759	CBM-8	3791
SB-5	3760	CBM-9	3794
SB-6	3761	CBM-10	3792
		CBM-11	3793
CBP-1	3766	CBM-12	3795
CBP-2	3767	CBM-13	3797
CBP-3	3768	CBM-14	3796
CBP-4	3769		
CBP-5	3770		
CBP-6	3771		
CBP-7	3772		
CBP-8	3773		

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